TECHNICAL NOTE

D-101

ROUGH-WATER DITCHING INVESTIGATION OF A MODEL OF A JET TRANSPORT WITH THE LANDING GEAR EXTENDED AND WITH VARIOUS DITCHING AIDS

By William C. Thompson

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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By William C. Thompson

SUMMARY

The rough-water ditching characteristics of a jet transport airplane with the landing gear extended and with various ditching aids were investigated at the Langley tank catapult. A dynamic model with certain portions of the model approximately scale strength was used to determine the probable ditching behavior and to some extent the resultant damage. The ditching aids included two sets of twin hydro-skis, two sets of twin hydrofoils, and a single hydrofoil. The rough-water tests were made in waves 4 feet high by 200 feet long and 4 feet high by 120 feet long (full scale). Data were obtained from visual observations, acceleration records, and motion pictures.

A rough-water ditching with the landing gear retracted will likely result in most of the fuselage bottom being torn away and the airplane sinking within a very short time. Ditching with the landing gear extended will likely result in a dive if the main gear does not fail or in a deep run with appreciable damage throughout the fuselage bottom if the main gear fails. Hydro-skis or hydrofoils may be used to improve the ditching performance and minimize the amount of damage to the fuselage bottom.

INTRODUCTION

A rough-water ditching investigation was made of a model of a typical jet transport airplane with the landing gear extended and with various ditching aids installed. This airplane (see fig. 1) was chosen as representative of the current high-speed multiengine jet transport designs. A previous model ditching investigation reported in reference 1 had shown that rather extensive damage occurred to the fuselage bottom when the model was ditched in calm water with no ditching aids and the landing gear retracted. The present tests were made to determine the effect of rough water and the effect of extending the landing gear on the amount of damage that occurred and on the behavior of the model. Tests with various hydro-skis and hydrofoils employed as ditching aids were made with the idea of eliminating or substantially reducing the amount of damage which normally occurred in a ditching.

APPARATUS AND PROCEDURE

Description of Model and Ditching Aids

The 0.043-scale model of a jet transport airplane shown in figure 2 with the landing gear extended and in figures 3, 4, and 5 with various ditching aids installed was used in the investigation. The model was constructed of balsa wood and spruce; the wing was covered with silk and the fuselage was covered with fiber glass and plastic. Internal ballast was used to obtain scale weights and moments of inertia. The model had a wing span of 5.59 feet and an overall length of 5.50 feet.

The landing flaps were installed so that they could be held in the down position at approximately scale strength. In order to accomplish this, a calibrated string was fastened between each flap fitting and a corresponding wing fitting so that water loads within ±10 percent of the ultimate design load (3,000-pound full-scale normal load applied near the trailing edge of a flap) would cause the string to break. When the scale-strength connections failed, the flaps rotated to the retracted position.

The engine nacelles were installed at approximately scale strength in a manner similar to that described for the landing flaps. Each nacelle strut had a parting line near the nacelle and the strut and the nacelle were connected with a calibrated string which failed within ±10 percent of the ultimate drag load (40,000 pounds, full scale). When the scale-strength connections failed, the nacelles became detached from the model.

The model was constructed so that portions of the fuselage bottom could be removed and replaced with approximately scale-strength sections. The scale-strength bottoms (ultimate strength of 10 pounds per square inch, full scale) were constructed of cardboard bulkheads and balsa-wood stringers and were covered with aluminum foil. Such a bottom is shown installed on the model in figure 2(c). Scale-strength bottoms were used to indicate the location and extent of damage which might occur in a ditching.

The landing gear was installed so that it could be held in the down position at approximately scale strength. A scale-strength shear pin was used to hold the landing-gear drag link so that loads within ±10 percent of the ultimate design load (88,000 pounds for each main gear and

26,000 pounds for the nose gear, full scale) applied at the axle and perpendicular to the main strut caused the shear pin to fail. When failure occurred, the gear rotated aft on the main-strut pivot. Figure 6 is a detail of the scale-strength landing-gear attachment.

Some preliminary tests were made with various sizes of ditching aids. The several configurations considered to be of most interest (fig. 7) were given further investigation and the results to be presented are from those more complete tests. The hydro-ski design selected (see figs. 7(a) and (b)) was a rectangular flat plate with a pointed trailing edge having an included angle of 30°. The angle of incidence of the hydro-skis was 10° with respect to the fuselage reference line. Two sets of hydro-skis were investigated; the larger hydro-skis had a loading of 2,500 pounds per square foot and the smaller hydro-skis had a loading of 4,400 pounds per square foot, full scale.

Further investigations were made with twin hydrofoils, a typical installation of which is shown in figure 7(c). This hydrofoil design embodies a circular-arc section with a square plan form and a sharp leading edge. The angle of incidence of the foils was 15° with respect to the fuselage reference line. Two sets of twin hydrofoils were investigated; the larger hydrofoils had a loading of 7,500 pounds per square foot and the smaller hydrofoils had a loading of 13,000 pounds per square foot, full scale. (See fig. 7(d).)

A single-hydrofoil installation is shown in figure 7(e). This hydrofoil was selected because the dihedral resulted in lower initial landing impact force. The hydrofoil was mounted on a single strut installed along the center line of the fuselage bottom. The angle of incidence was 15° with respect to the fuselage bottom surface. Details of the single hydrofoil are shown in figure 7(f). The single hydrofoil had a loading of 8,300 pounds per square foot, full scale.

Test Methods and Equipment

Tests were made at the Langley tank catapult (fig. 8). The model was ditched by catapulting it into the air to permit a free glide onto the water. The model left the launching carriage at scale speed and at the desired landing attitude with the control surfaces set so that the attitude did not change appreciably in flight. The behavior was recorded by a motion-picture camera and from visual observations. Accelerations were recorded by single-component strain-gage type of accelerometers installed in the forward portion of the passenger compartment. The natural frequencies of the accelerometers and recording galvanometers were 160 cycles per second and 150 cycles per second, respectively. Both were damped to about 70 percent of critical damping. The longitudinal decelerations and the normal accelerations were measured parallel and perpendicular, respectively, to the fuselage reference line. (See fig. 1.) The static normal accelerometer reading was 1 g. The model was landed into oncoming waves which were generated by the tank wave-making machine.

Test Conditions

The model was investigated at the following test conditions (all values are full scale):

Weight - A gross weight of 225,000 pounds was used for the investigation.

Center of gravity - The center of gravity was located at 26 percent of the mean aerodynamic chord and 60.7 inches above the fuselage bottom surface.

Moments of inertia - The model was ballasted to approximate the following values of moments of inertia:

Roll, slug-ft^2	1,900,000
Pitch, slug-ft^2	3,200,000
Yaw, slug-ft^2	4,900,000

Landing attitude - All tests were made at a 12° landing attitude. The attitude was measured with respect to the fuselage reference line and the calm-water surface.

Flaps - Tests were made with the landing flaps in the down 50° position and these flaps were attached at scale strength.

Landing speed - The model was airborne when launched and at a landing speed of approximately 120 knots.

Water conditions - Tests were made simulating the following water conditions:

(a) Calm

(b) Waves 4 feet high by 120 feet long (crest to crest)

(c) Waves 4 feet high by 200 feet long (crest to crest)

Fuselage conditions - The model was tested with the following fuselage conditions:

(a) No damage simulated (figs. 2(a) and (b))

(b) Scale-strength fuselage bottom installed (figs. 2(c) and 3)

Landing gear - Tests were made with the landing gear both retracted and extended. When the gear was extended, a scale-strength drag-link pin was used (fig. 6).

Ditching aids - The model was tested in the following configurations, each representing a type of ditching aid:

(a) Twin hydro-skis installed (fig. 3)

(b) Twin hydrofoils installed (fig. 4)

(c) Single hydrofoil installed (fig. 5)

RESULTS AND DISCUSSION

A summary of the results of the investigation is presented in tables I and II; all values are full scale. The notations used in the tables are defined as follows:

Dived - The forward portion of the fuselage and part of the wing submerged, and the angle between the water surface and the fuselage reference line was 15° or greater.

Ran deeply - The model moved through the water partially submerged and exhibited a tendency to dive although the attitude did not change appreciably.

Ran smoothly - The model made no apparent oscillation about any axis and gradually settled into the water as the forward velocity decreased.

Trimmed down - The attitude of the model decreased shortly after contact with the water.

Landing Gear Retracted

When the model was ditched in calm water with the landing gear retracted (ref. 1), about one-half of the scale-strength bottom was torn away. When the model was ditched in waves with the landing gear retracted, practically all of the scale-strength fuselage bottom was torn away as shown in figure 9(a). A full-scale airplane sustaining such damage would most likely sink within a very short time. Ditchings into the 4-foot by 120-foot waves resulted in a maximum normal acceleration of 4g. (See table I.) The model did not penetrate the waves deeply but tended to bounce from crest to crest until considerable forward speed was lost; then, the model followed the wave contours for the remainder of the run. The total length of landing run was about 600 feet, full scale. The maximum normal acceleration in the 4-foot by 200-foot waves was about 8g as the model ploughed into the forward slope of the waves. The distance from initial water contact until the forward motion of the model stopped was about 550 feet, full scale.

Landing Gear Extended

Nose gear.- The nose landing gear always failed in calm- or rough-water ditchings. There was no appreciable difference in behavior or damage to the fuselage bottom whether the model was ditched with the nose gear extended or retracted.

Main gear.- The scale-strength attachments for the main landing gear were of such strength that sometimes they failed and sometimes they did not. When the main gear failed, the model ran deeply and there was appreciable damage to the scale-strength fuselage bottom. (See fig. 9(b).) The maximum normal acceleration was about 6g and the maximum longitudinal deceleration was about $5\frac{1}{2}$g. The total length of the landing run was about 450 feet. These results when compared with those for all wheels retracted indicate less but still appreciable damage, about 2g less normal acceleration and a landing run about 100 feet shorter. When the main gear did not fail, the model usually dived and there was a large hole torn in the bottom of the nose section of the fuselage as shown in figure 9(c). However, such damage accompanied by a diving motion would most likely cause extremely rapid flooding of the entire fuselage. There was little difference in behavior or damage whether the model was ditched in calm water or waves 4 feet high. (See table I.)

On the basis of these model tests, it appears that if the main gear fails there is little choice between ditching with the gear extended or retracted; but, if the main gear does not fail, a more dangerous behavior results. Therefore, it is recommended that the gear remain retracted in a ditching.

Hydro-Skis Installed

When the model with the twin hydro-skis (fig. 7(a)) having a loading of 2,500 pounds per square foot was ditched into waves 4 feet high, the result was a fairly smooth run with very little damage to the fuselage bottom as may be seen in figure 9(d). Ditchings in either wave condition resulted in a maximum normal acceleration of about $3\frac{1}{2}$g and a total length of landing run of about 1,280 feet (see table II). With the smaller twin hydro-skis which had a loading of 4,400 pounds per square foot, the model trimmed down, ran smoothly, and ran deeply. There was moderate damage to the midportion of the scale-strength fuselage bottom (fig. 9(e)). The maximum normal acceleration was about $3\frac{1}{2}$g, which was the same as was obtained with the larger hydro-skis. However, the total length of landing run was about 600 feet, which was about one-half that for the larger hydro-skis.

Hydrofoils Installed

Tests with the larger twin-hydrofoil installation (fig. 7(c)) having a loading of 7,500 pounds per square foot resulted in a fairly rough ditching since the hydrofoils did not penetrate the waves but rather bounced along the crests until most of the forward velocity was lost. The total length of landing run was about 1,160 feet and the maximum normal acceleration was 6g, which was about twice that obtained with any of the other ditching aids. There was moderate damage to the fuselage bottom just aft of the wing as may be seen in figure 9(f).

Tests with the smaller twin-hydrofoil installation having a loading of 13,000 pounds per square foot resulted in fairly smooth runs with the hydrofoils penetrating the waves. There was more damage to the rear portion of the fuselage bottom than occurred with the larger hydrofoils (fig. 9(g)). The maximum normal acceleration was 3g in a total length of landing run of about 900 feet.

When the model was ditched with the single-hydrofoil installation (fig. 7(e)), the hydrofoil penetrated the wave crests and ran smoothly. Damage to the scale-strength fuselage bottom consisted of a section of skin about 8 feet square torn away just aft of the wing. This damage was considered moderate since the supporting structure remained intact and only the skin was torn away. Figure 9(h) shows typical damage that occurred. The maximum normal acceleration was about $3\frac{1}{2}$g and the total length of landing run was about 1,100 feet.

CONCLUSIONS

From the results of the rough-water ditching investigation of a dynamic model of a jet transport, the following conclusions were drawn:

1. Ditching with the landing gear retracted will likely result in most of the fuselage bottom being torn away and the airplane sinking within a very short time.

2. Ditching with the landing gear extended will likely result in a dive if the main gear does not fail or in a deep run with appreciable damage throughout the fuselage bottom if the main gear fails.

3. Hydro-skis or hydrofoils may be used to improve the ditching performance and minimize the amount of damage to the fuselage bottom.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., July 14, 1959.

REFERENCE

1. Thompson, William C.: Model Ditching Investigation of a Jet Transport Airplane With Various Engine Installations. NACA RM L56G10, 1956.

TABLE I

SUMMARY OF RESULTS OF DITCHING TESTS WITH A DYNAMIC MODEL OF A

JET TRANSPORT AIRPLANE WITH AND WITHOUT LANDING GEAR

[Scale-strength nacelle struts, flap connections, and landing gear drag links; landing attitude, 12°; flaps down, 50°; gross weight, 225,000 pounds; landing speed, 120 knots; static normal accelerometer reading, 1 g. All values are full scale.]

Configuration	Type of fuselage bottom	Wave size, ft	Maximum normal acceleration, g	Maximum longitudinal deceleration, g	Length of landing run, ft	Comments
Landing gear extended; main gear did not fail during ditching	Nondamageable	Calm	3	$4\frac{1}{2}$	220	Dived
		4 by 120	3	$4\frac{1}{2}$	300	
		4 by 200	5	4	290	
	Scale-strength	Calm	4	$5\frac{1}{2}$	375	Dived; large hole in bottom of front portion of fuselage causing rapid flooding
		4 by 120	$3\frac{1}{2}$	5	260	
		4 by 200	$4\frac{1}{2}$	5	350	
Landing gear extended; main gear failed during ditching	Nondamageable	4 by 120	$5\frac{1}{2}$	5	500	Ran deeply
		4 by 200	5	$3\frac{1}{2}$	540	
	Scale-strength	4 by 120	$4\frac{1}{2}$	5	470	Ran deeply; appreciable damage throughout the length of the fuselage bottom
		4 by 120	6	$5\frac{1}{2}$	450	
Landing gear retracted	Scale-strength	4 by 120	4		600	Bounced on wave crests; most of bottom torn away
		4 by 200	8		550	Very rough initial impact; ran deeply; most of bottom torn away

TABLE II

SUMMARY OF RESULTS OF DITCHING TESTS WITH A DYNAMIC MODEL OF A

JET TRANSPORT AIRPLANE USING VARIOUS DITCHING AIDS

[Scale-strength fuselage bottom, nacelle struts, and flap connections; landing attitude, 12°; flaps down, 50°; gross weight, 225,000 pounds; landing speed, 120 knots; static normal accelerometer reading, 1 g. All values are full scale.]

Ditching aid and loading, lb/sq ft	Wave size, ft	Maximum normal acceleration, g	Length of landing run, ft	Comments
Twin hydro-ski (2,500)	4 by 120	3	1,280	Ran smoothly; very little damage to fuselage bottom
	4 by 200	$3\frac{1}{2}$	1,280	Ran smoothly; very little damage to fuselage bottom
Twin hydro-ski (4,400)	4 by 120	$2\frac{1}{2}$	580	Trimmed down, ran smoothly, ran deeply; moderate damage to midportion of fuselage bottom
	4 by 200	$3\frac{1}{2}$	600	Trimmed down, nose ploughed through wave crests; moderate damage to midportion of fuselage bottom
Twin hydrofoil (7,500)	4 by 120	6	1,160	Bounced along on wave crests; moderate damage to fuselage bottom just aft of the wing
Twin hydrofoil (13,000)	4 by 120	3	900	Ran fairly smooth; appreciable damage to rear part of fuselage bottom
	4 by 200	3	900	Ran fairly smooth, penetrated wave crests; appreciable damage to rear part of fuselage bottom
Single hydrofoil (8,300)	4 by 120	3	1,070	Ran smoothly; moderate damage to fuselage bottom just aft of the wing
	4 by 200	$3\frac{1}{2}$	1,160	Ran fairly smooth; moderate damage to fuselage bottom just aft of the wing

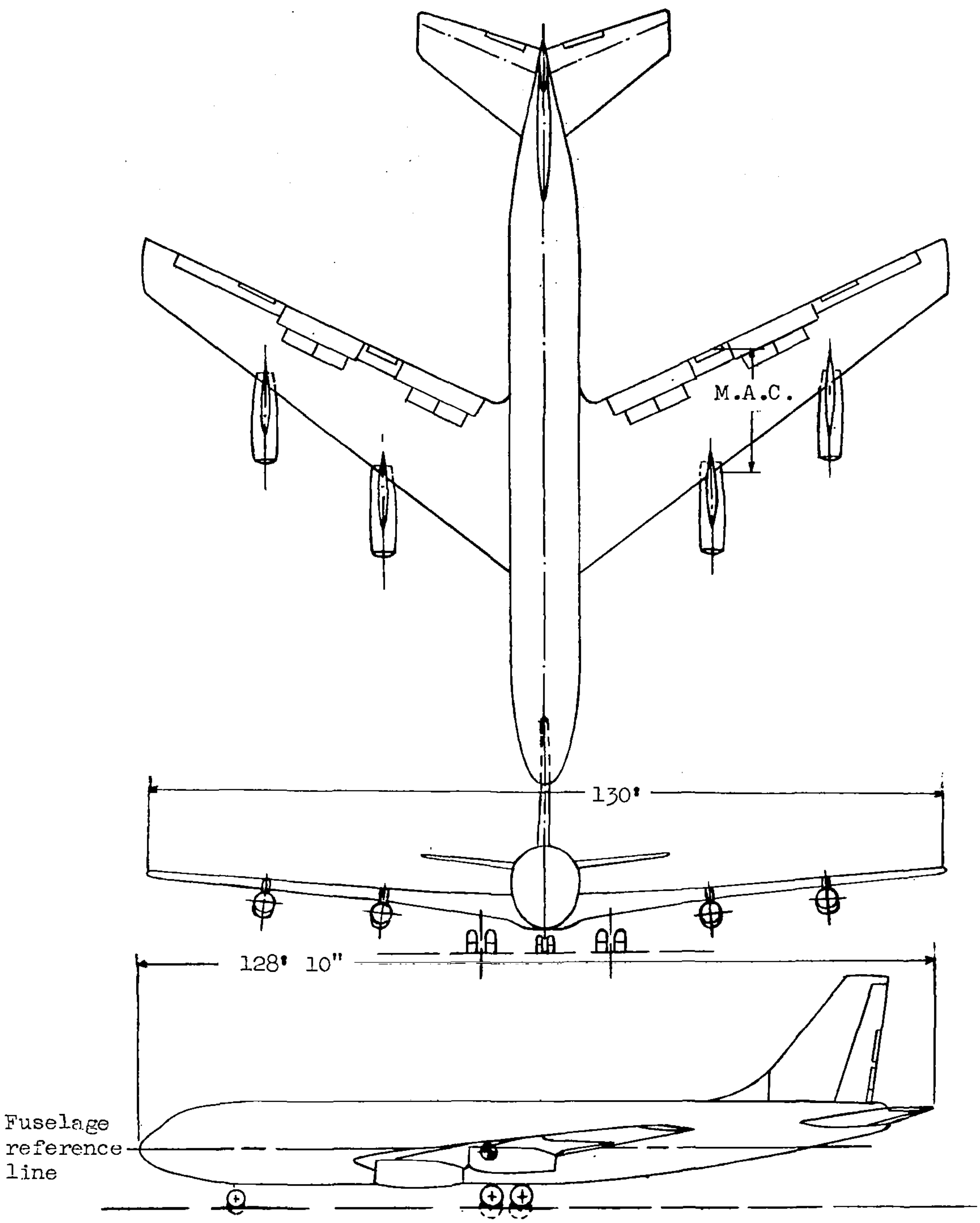
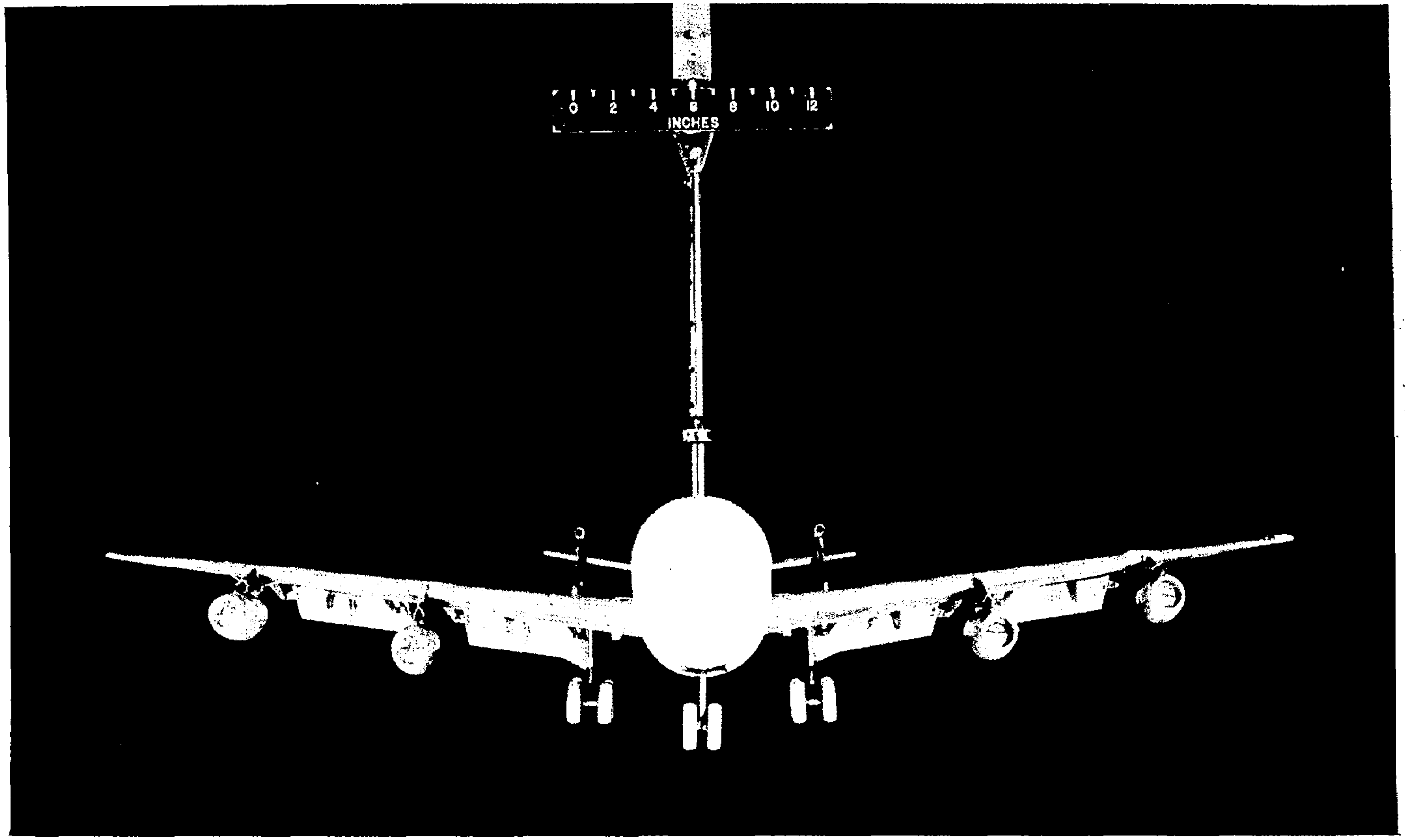
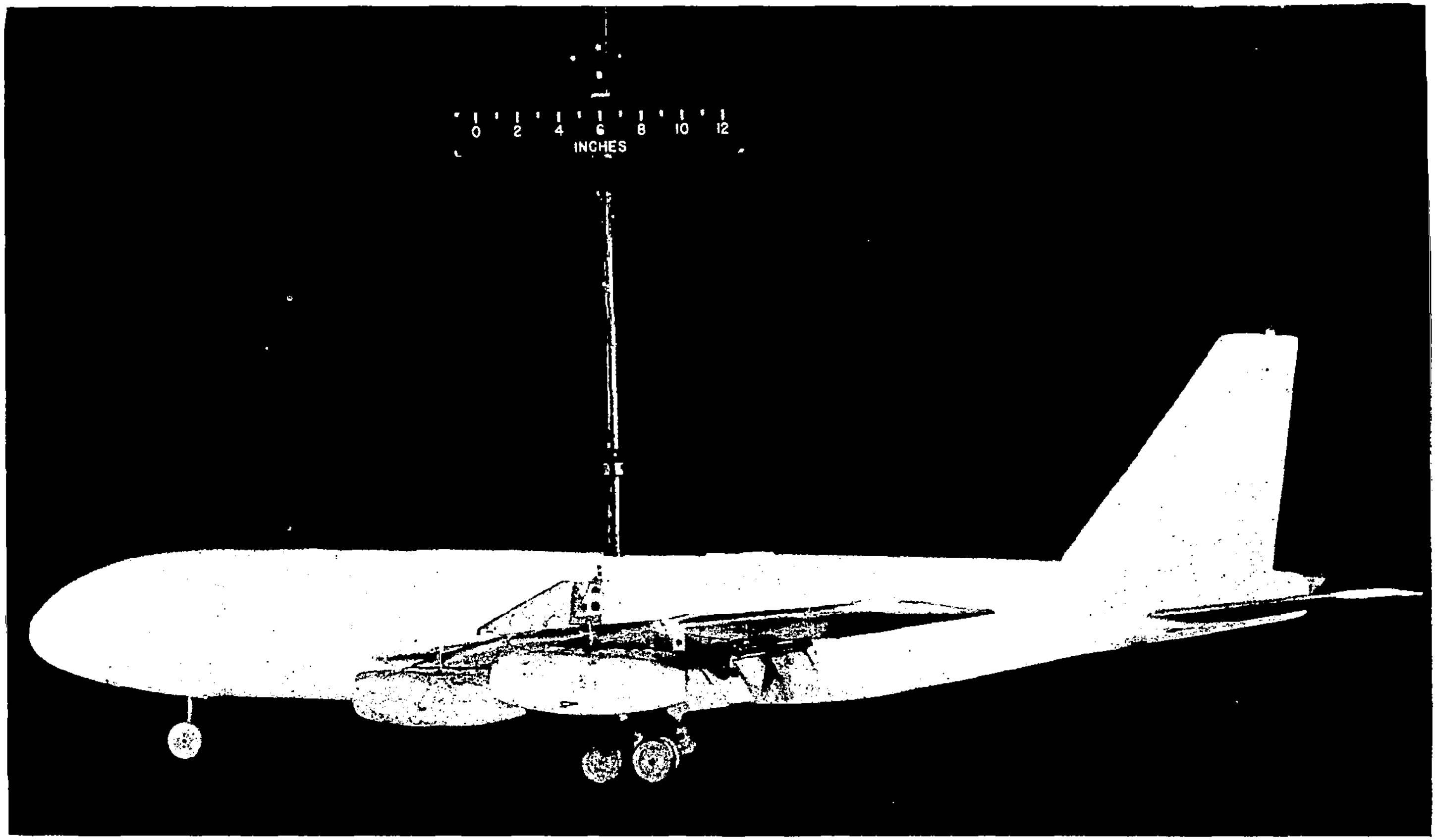


Figure 1.- Three-view drawing of a jet transport airplane with landing gear extended.



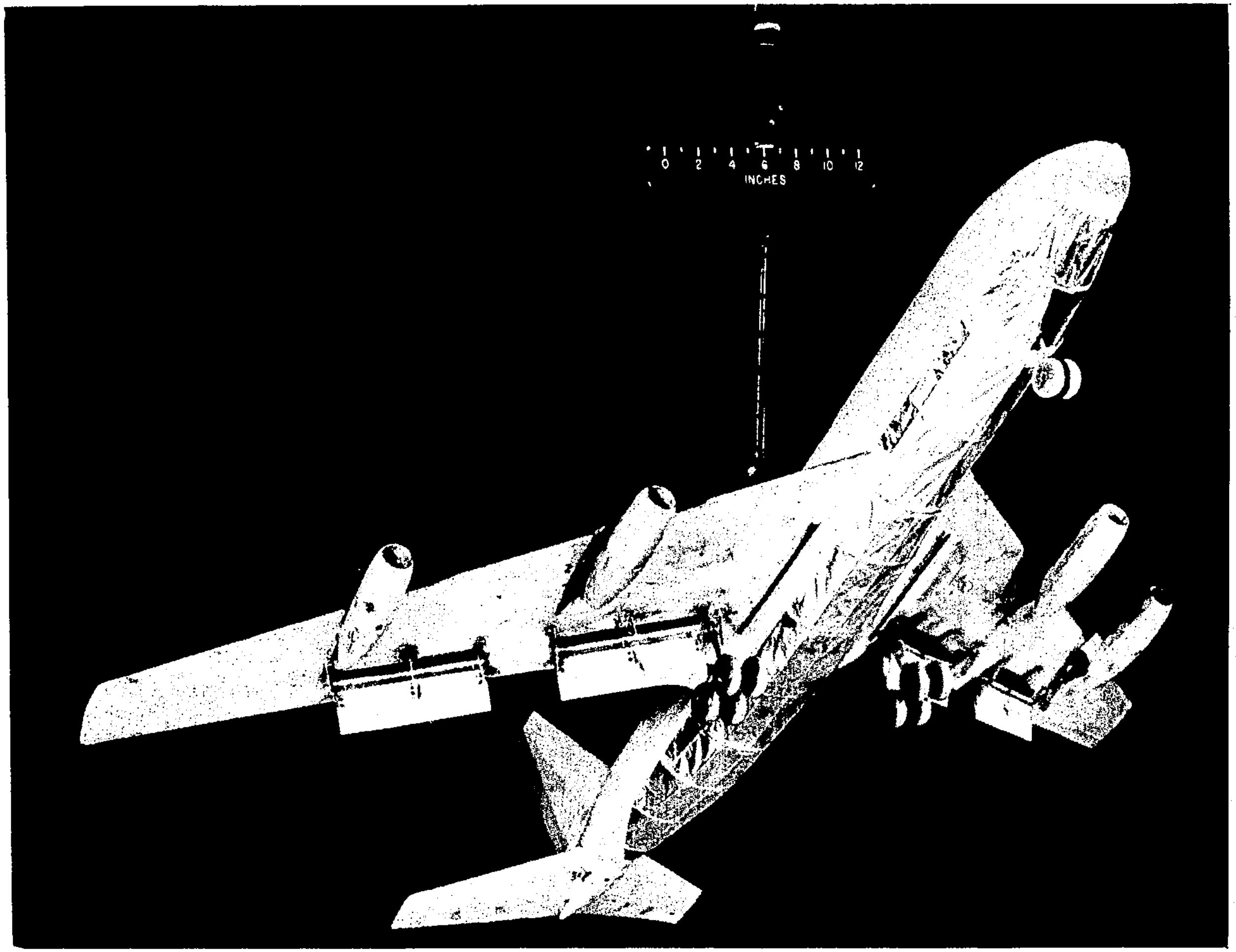
(a) Front view. L-57-4246

Figure 2.- Model with landing gear extended.



(b) Side view. L-57-4240

Figure 2.- Continued.



L-57-4247
(c) Three-quarter bottom view with scale-strength fuselage bottom installed.

Figure 2.- Concluded.

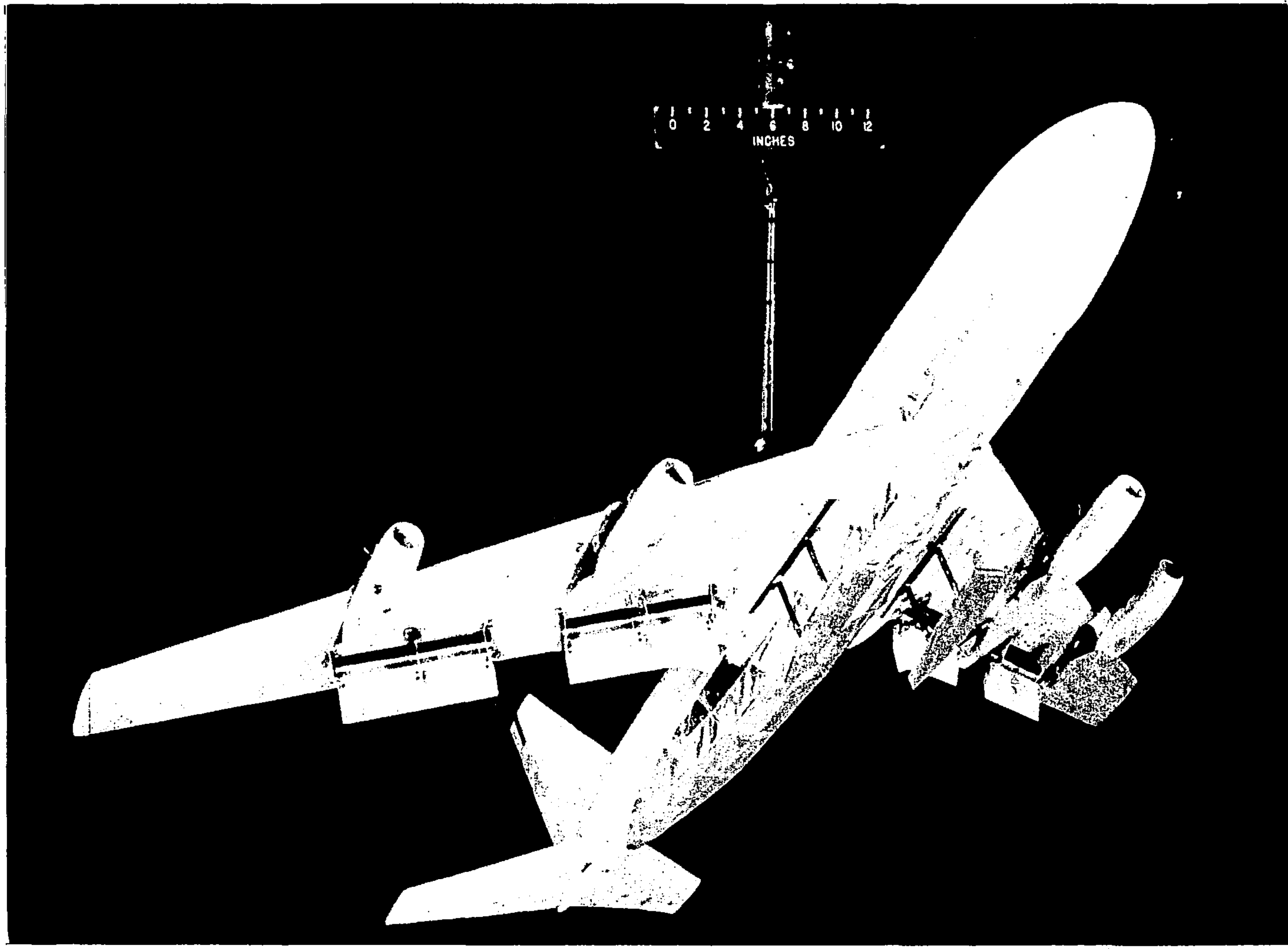


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Figure 3.- Model with twin hydro-skis and scale-strength fuselage bottom installed.

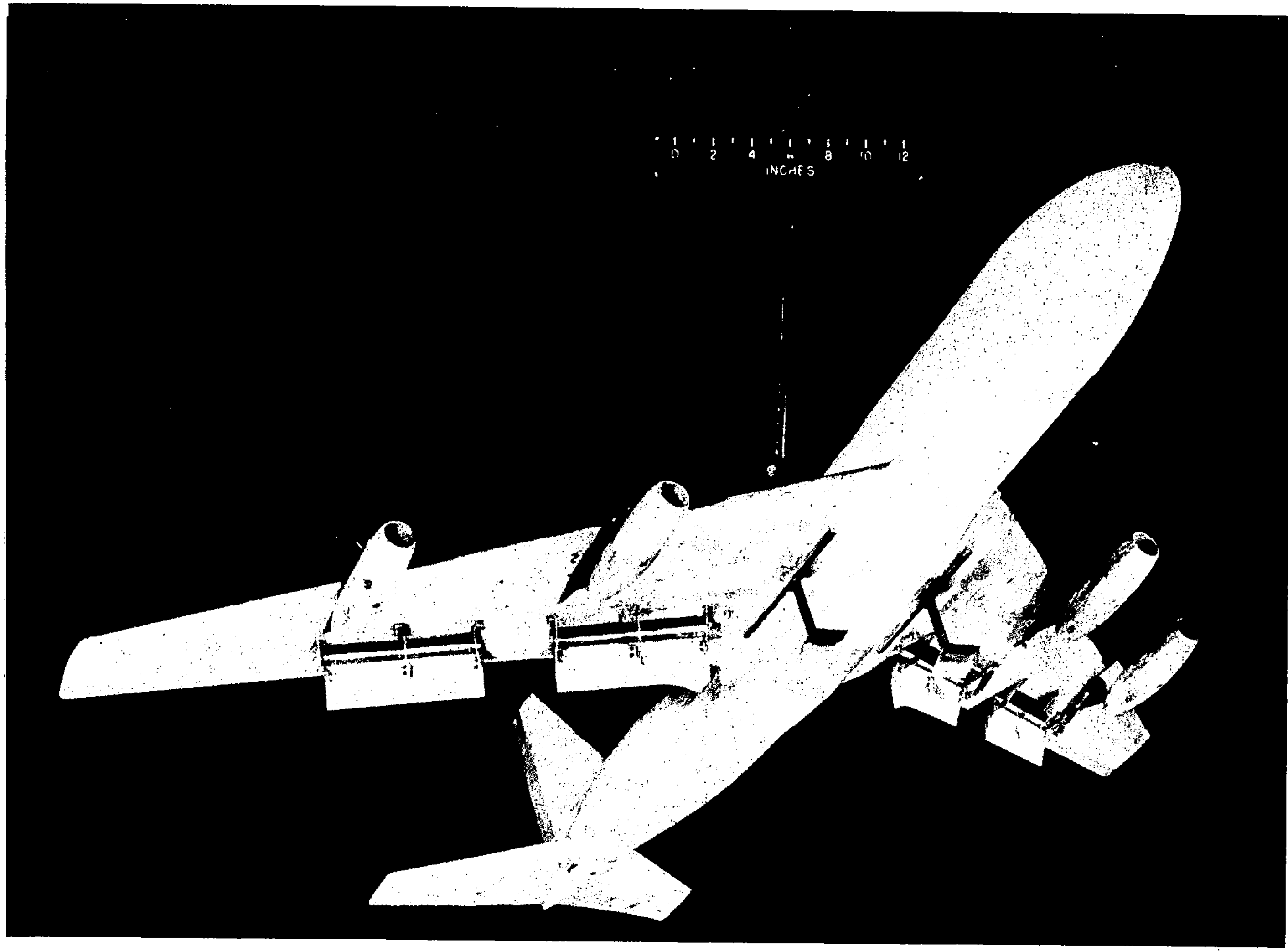


Figure 4.- Model with twin hydrofoils installed. L-57-4243

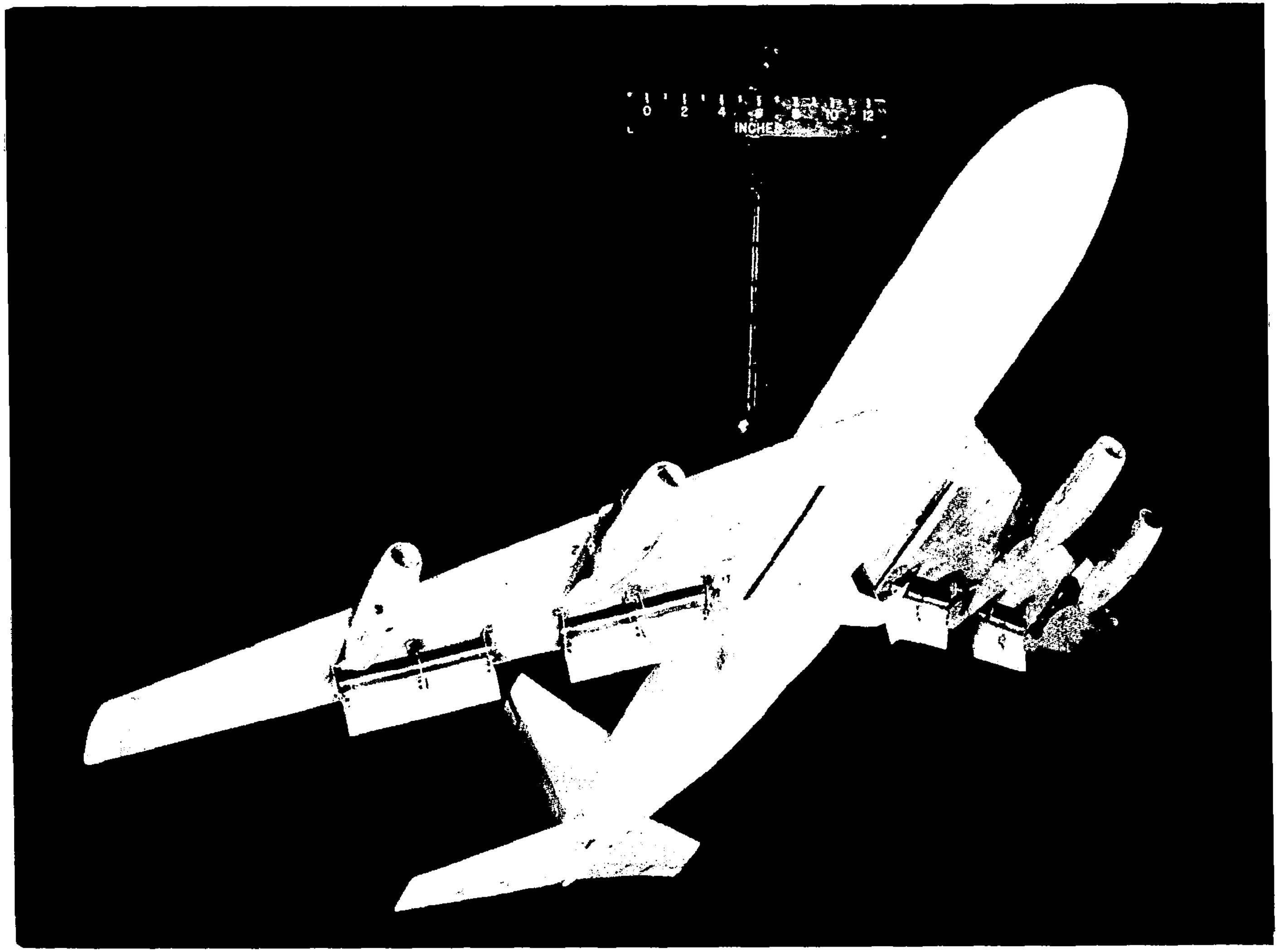


Figure 5.- Model with single hydrofoil installed. L-57-4251

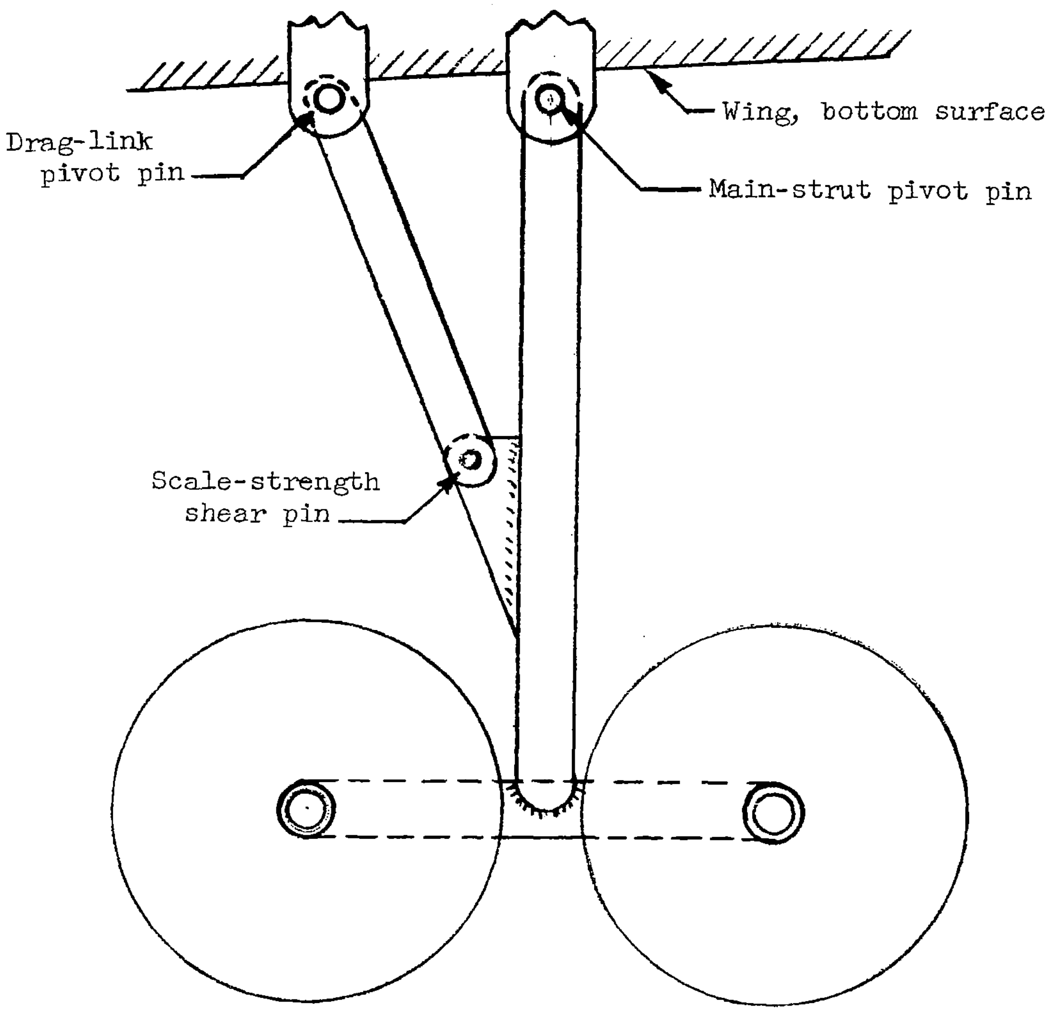
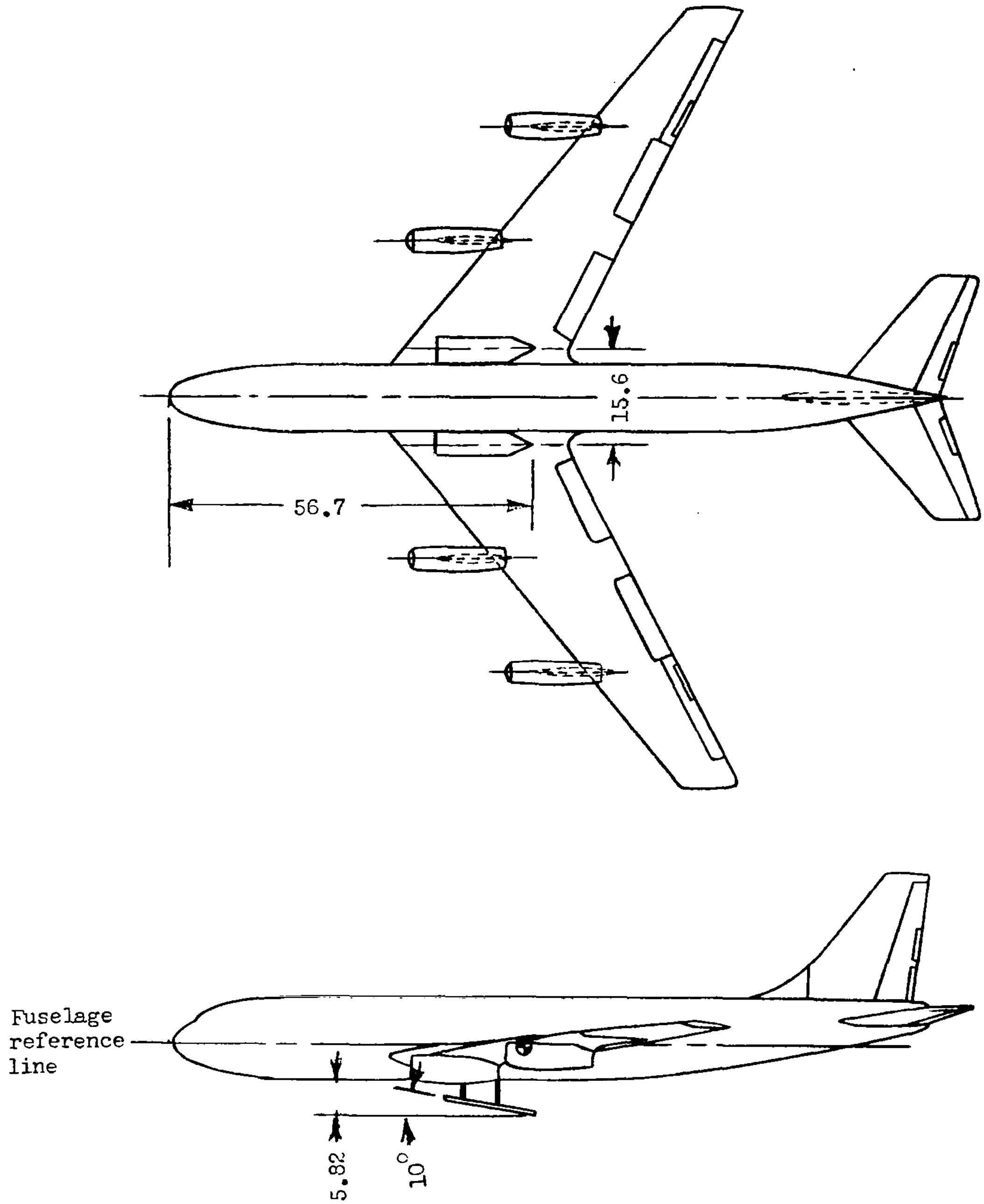
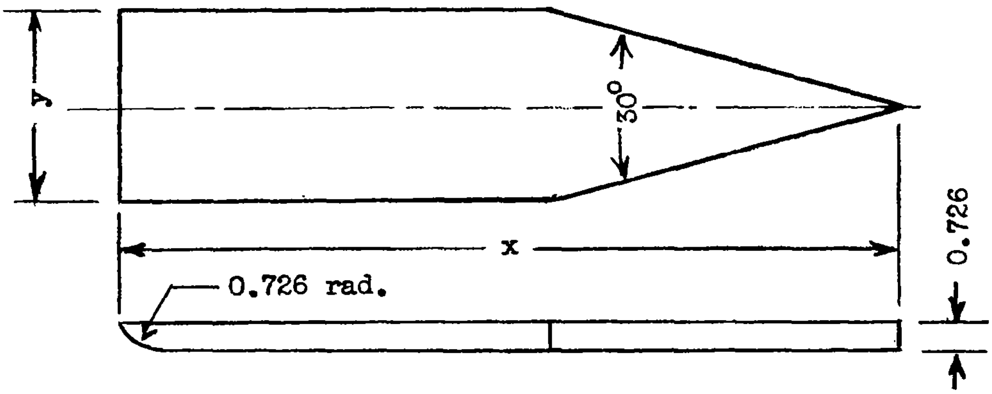


Figure 6.- Detail of scale-strength landing gear attachment.



(a) Twin-hydro-ski installation.

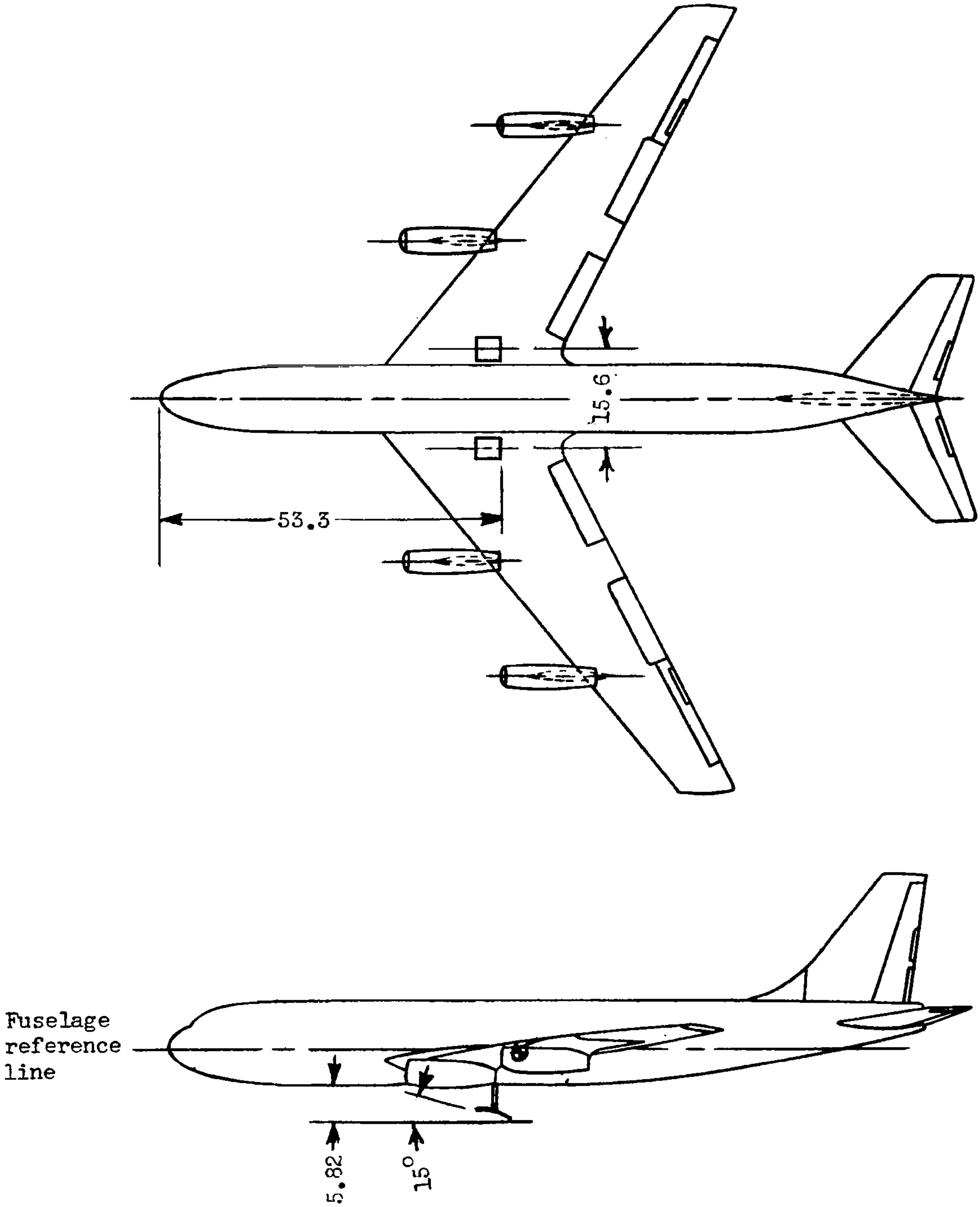
Figure 7.- Ditching aid configurations. Dimensions are in feet (full scale).



Loading, lb/sq ft	x	y
2,500	15.50	3.88
4,400	11.62	2.91

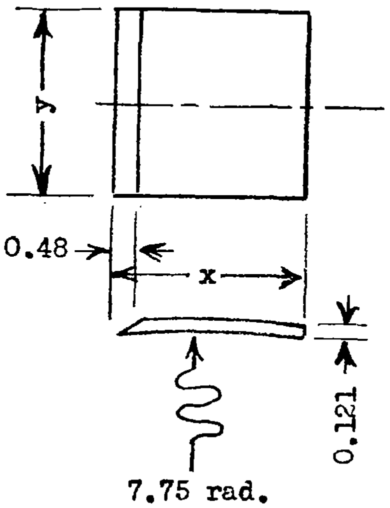
(b) Twin-hydro-ski details.

Figure 7.- Continued.



(c) Twin-hydrofoil installation.

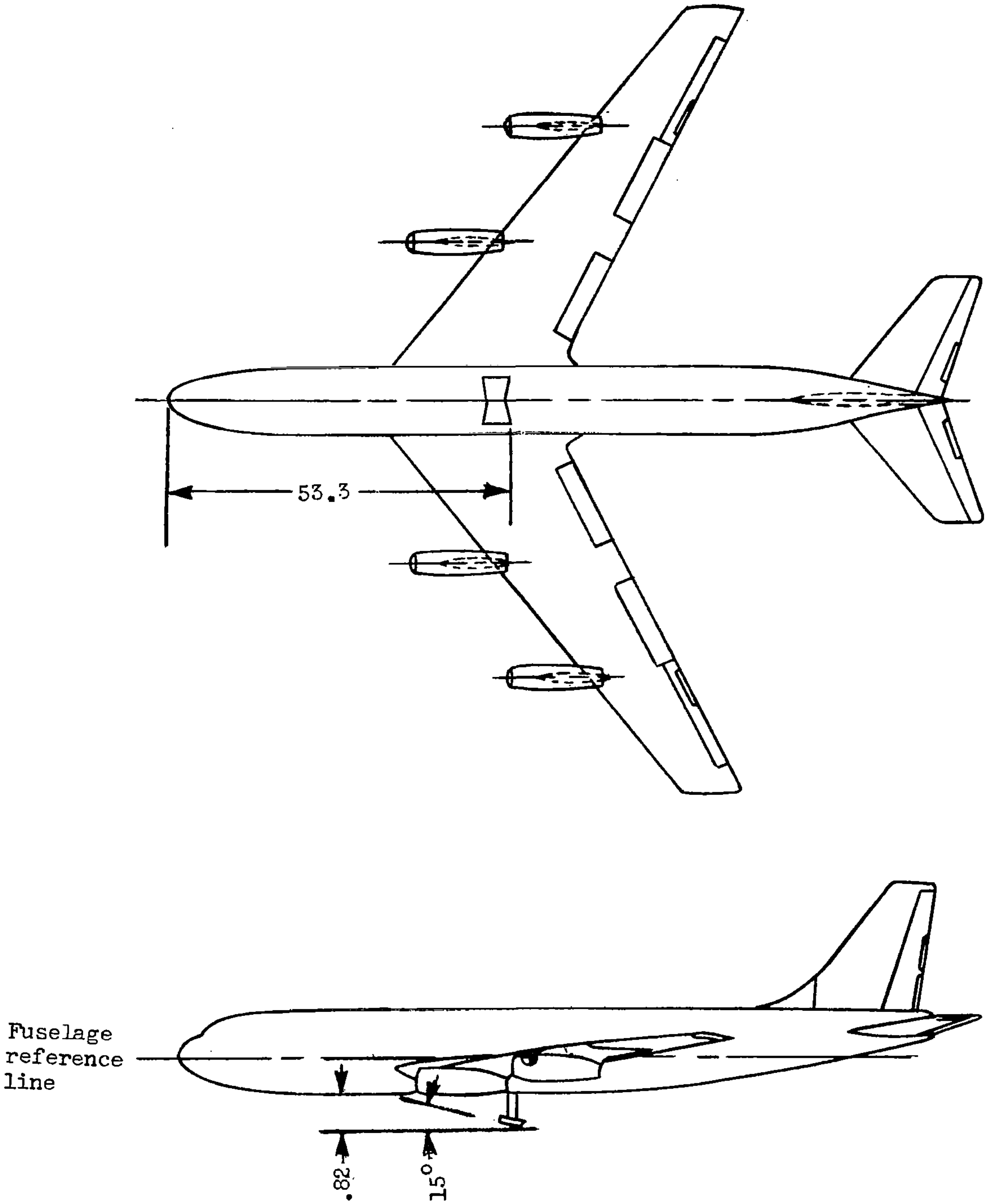
Figure 7.- Continued.



Loading, lb/sq ft	x	y
7,500	3.88	3.88
13,000	2.91	2.91

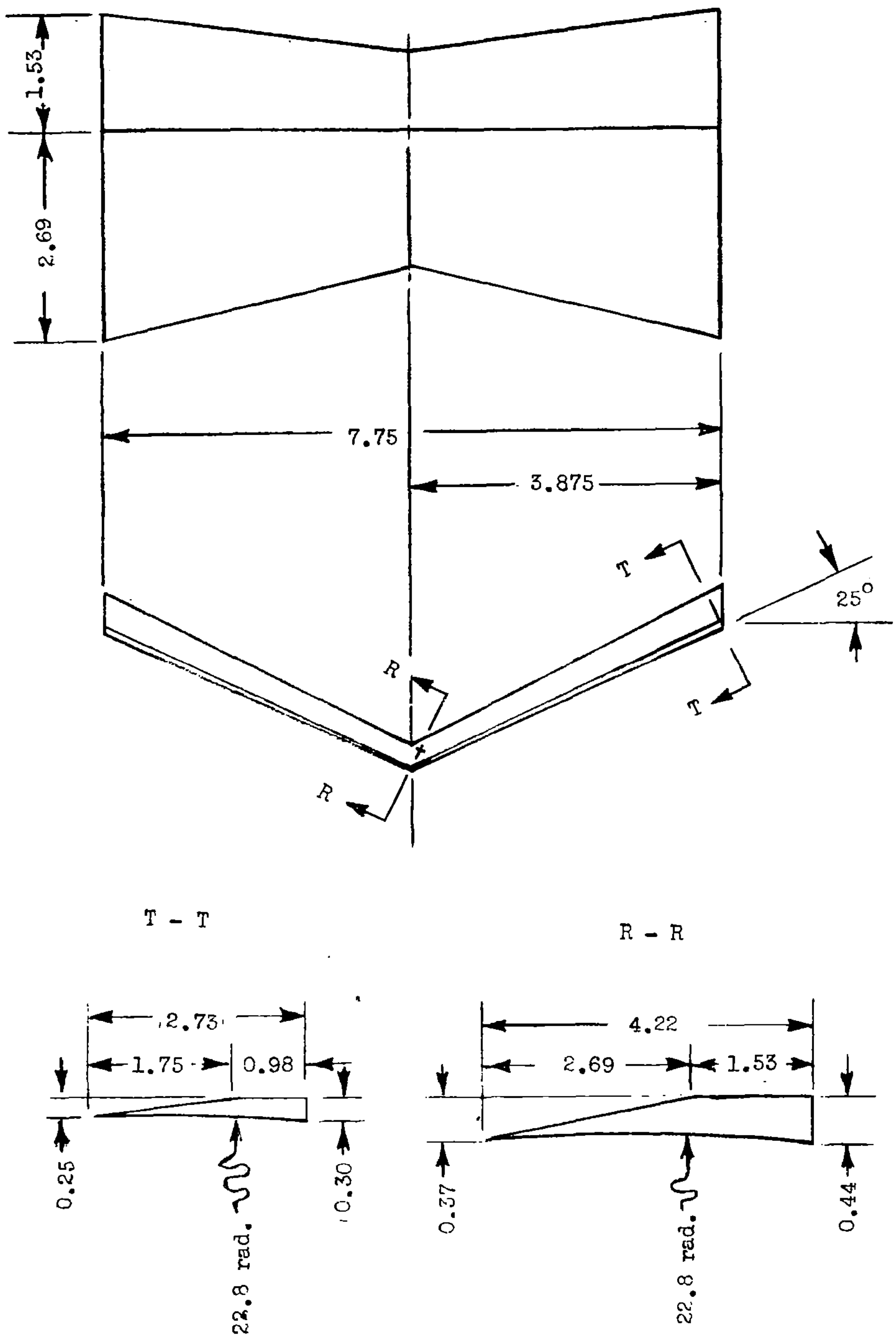
(d) Twin-hydrofoil details.

Figure 7.- Continued.



(e) Single-hydrofoil installation.

Figure 7.- Continued.



(f) Single-hydrofoil details.

Figure 7.- Concluded.

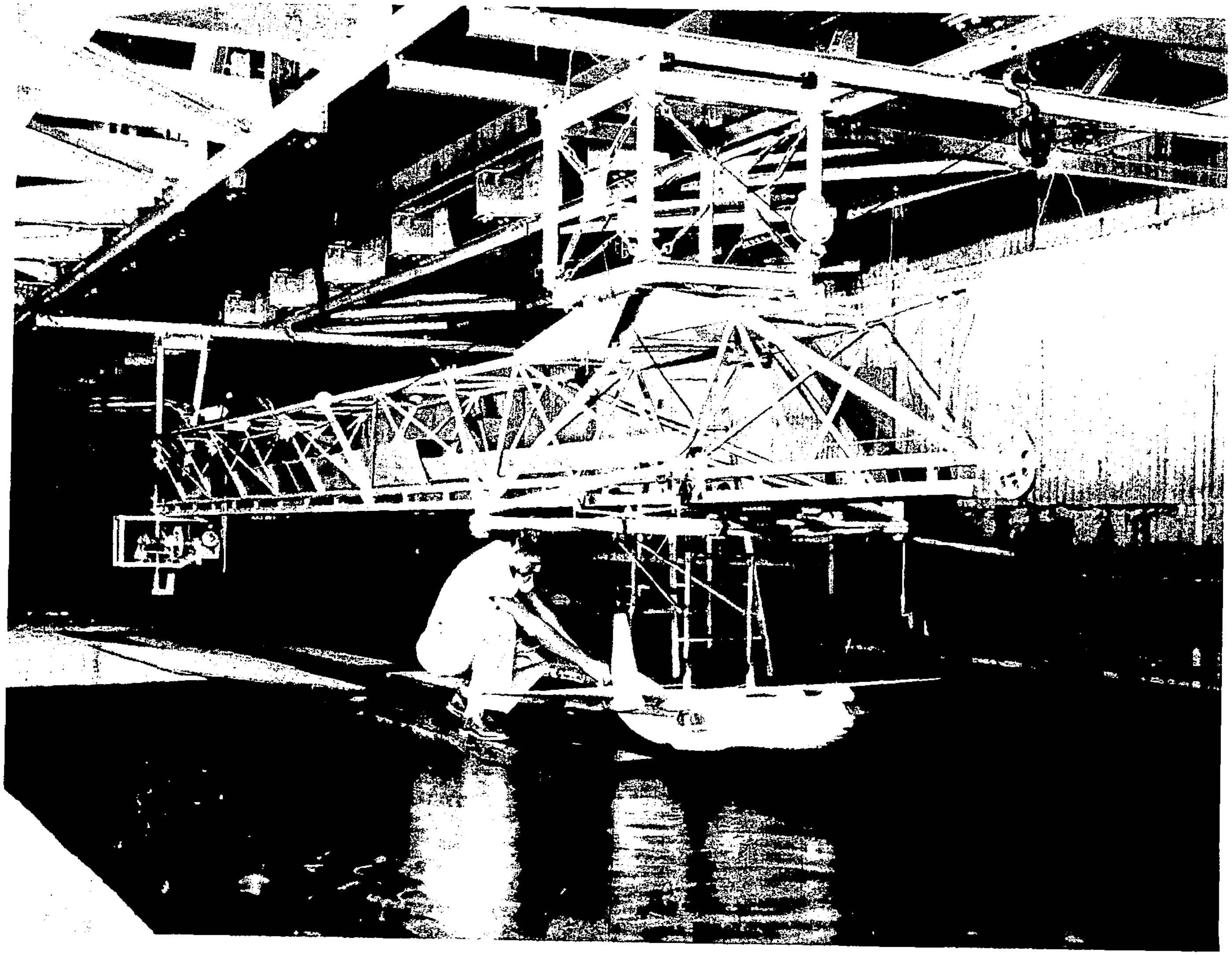
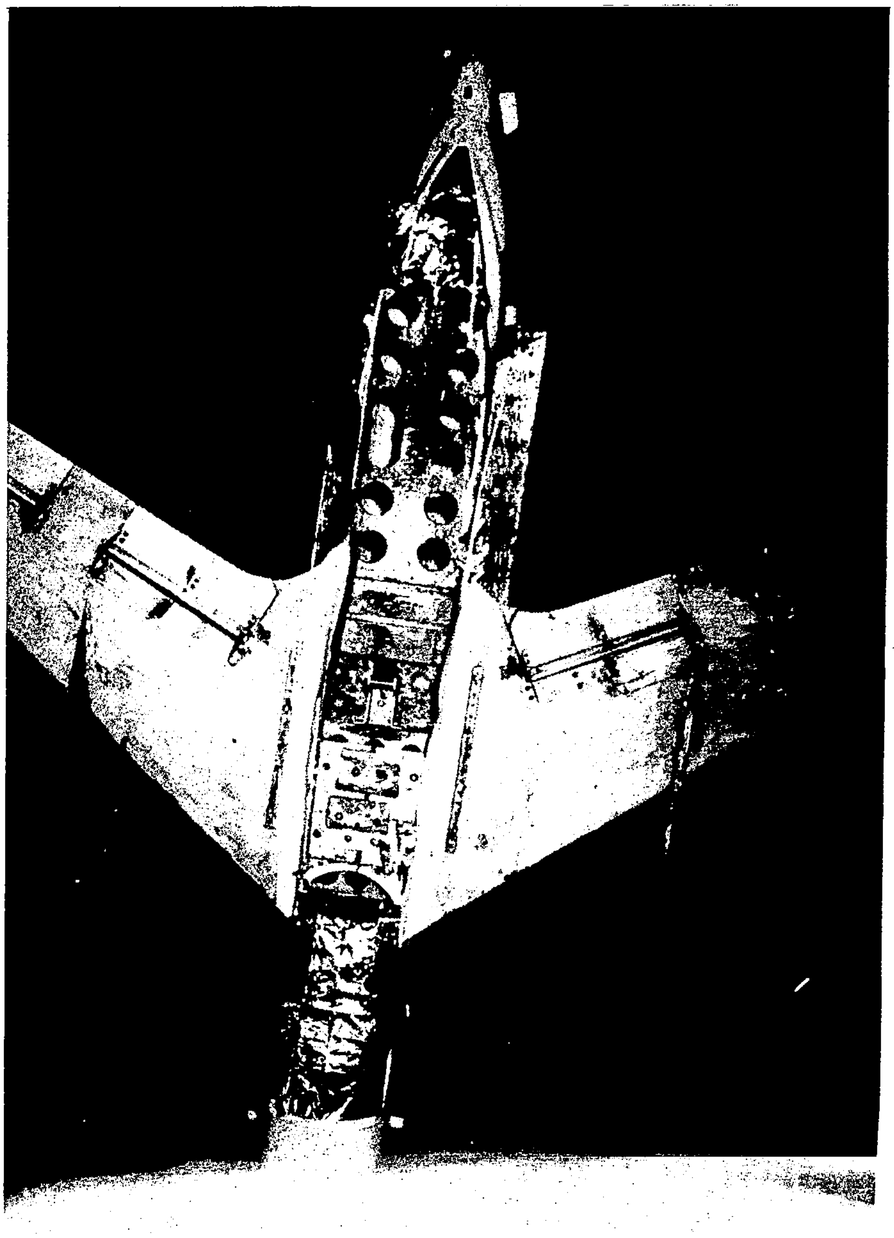


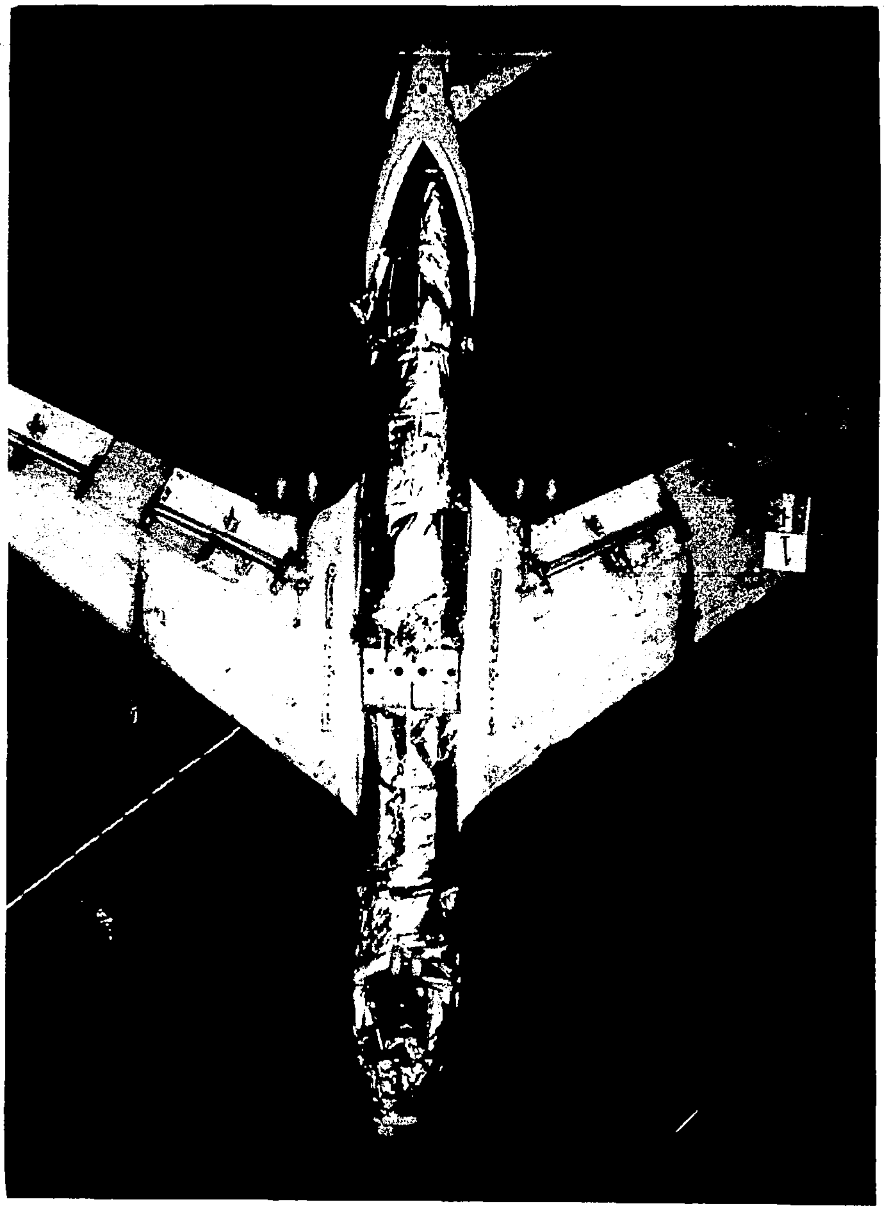
Figure 8.- The Langley tank catapult with a model attached. L-94761



L-59-3089

(a) Landing gear retracted; no ditching aids. Most of bottom torn away.

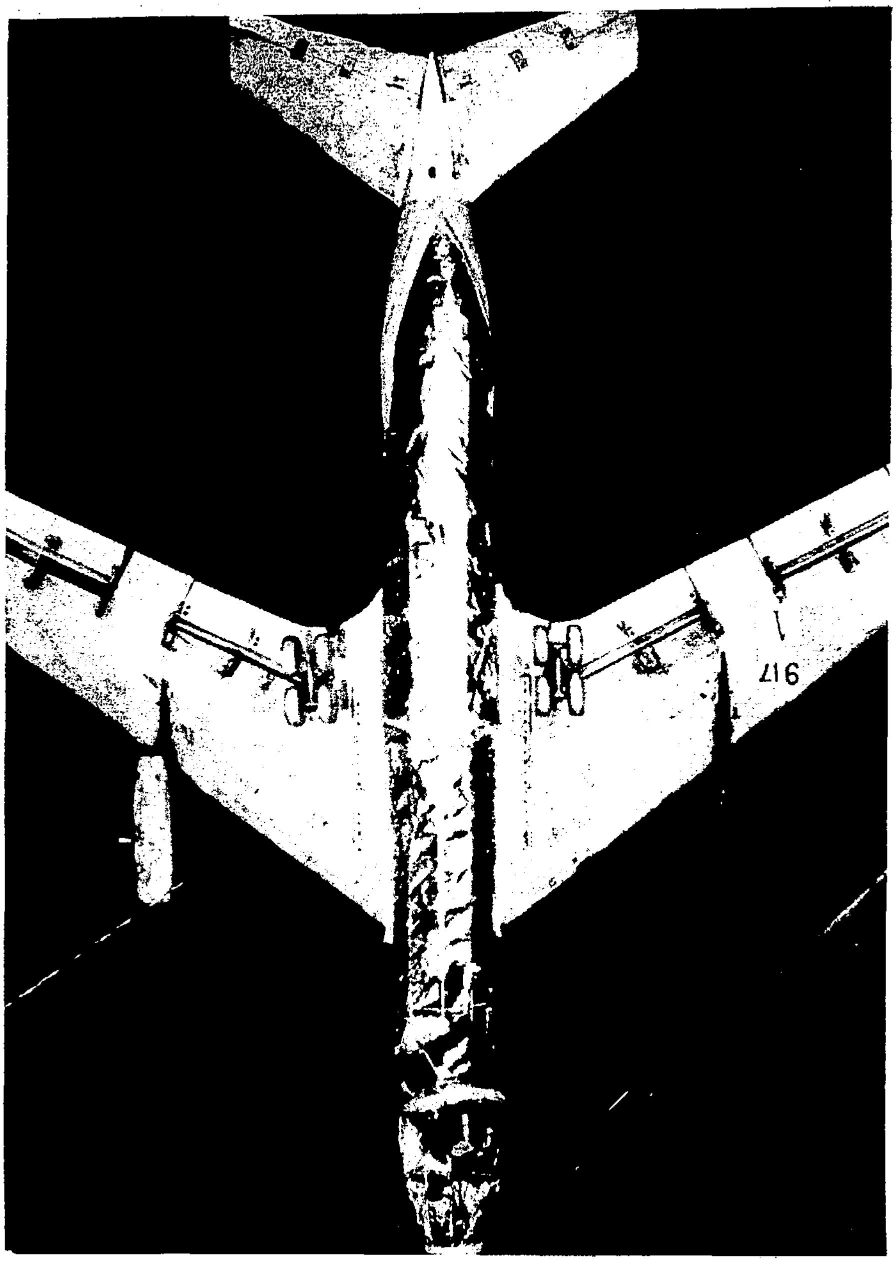
Figure 9.- Typical damage to the scale-strength fuselage bottom during rough-water ditchings.



L-59-3090

(b) Landing gear down; all failed; appreciable damage throughout the length of the fuselage.

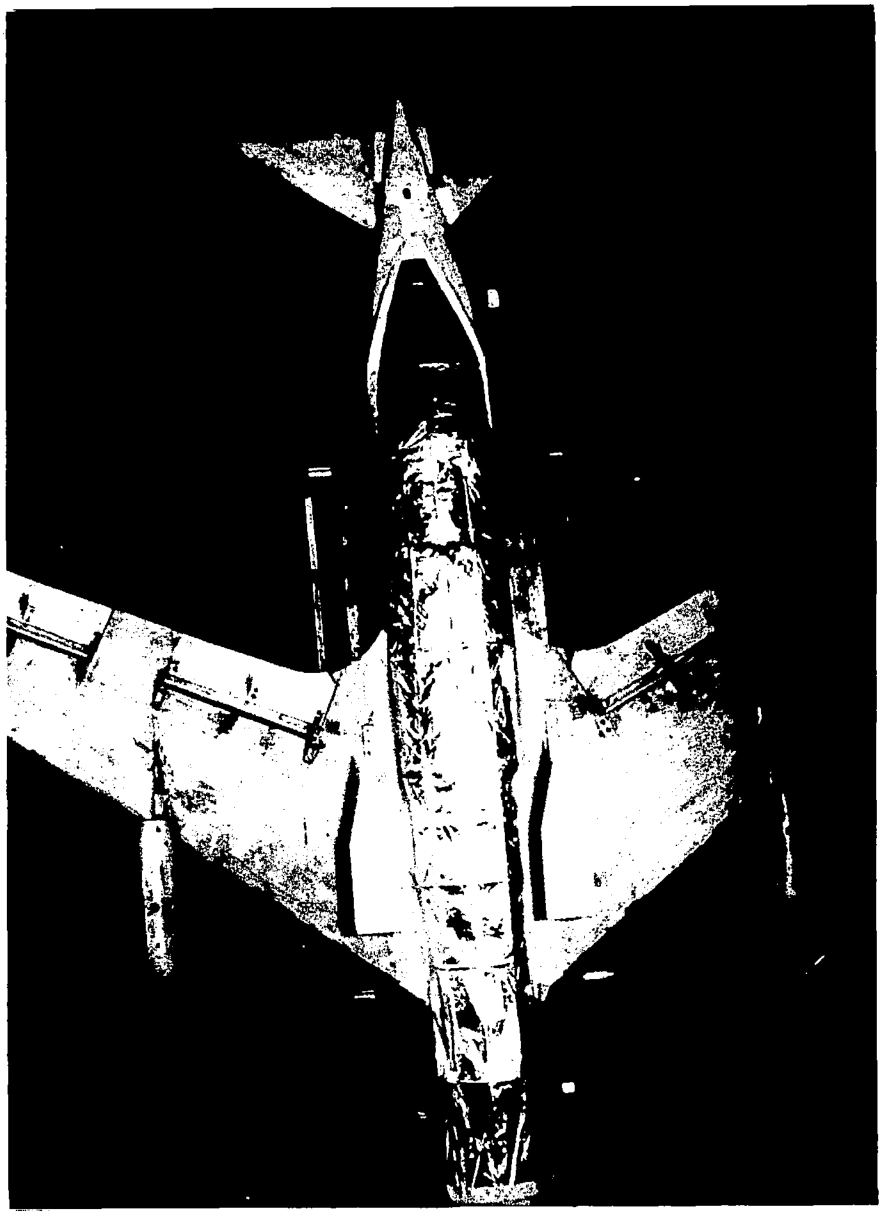
Figure 9.- Continued.



L-59-3091

(c) Landing gear down; main gear did not fail. Moderate damage in nose section.

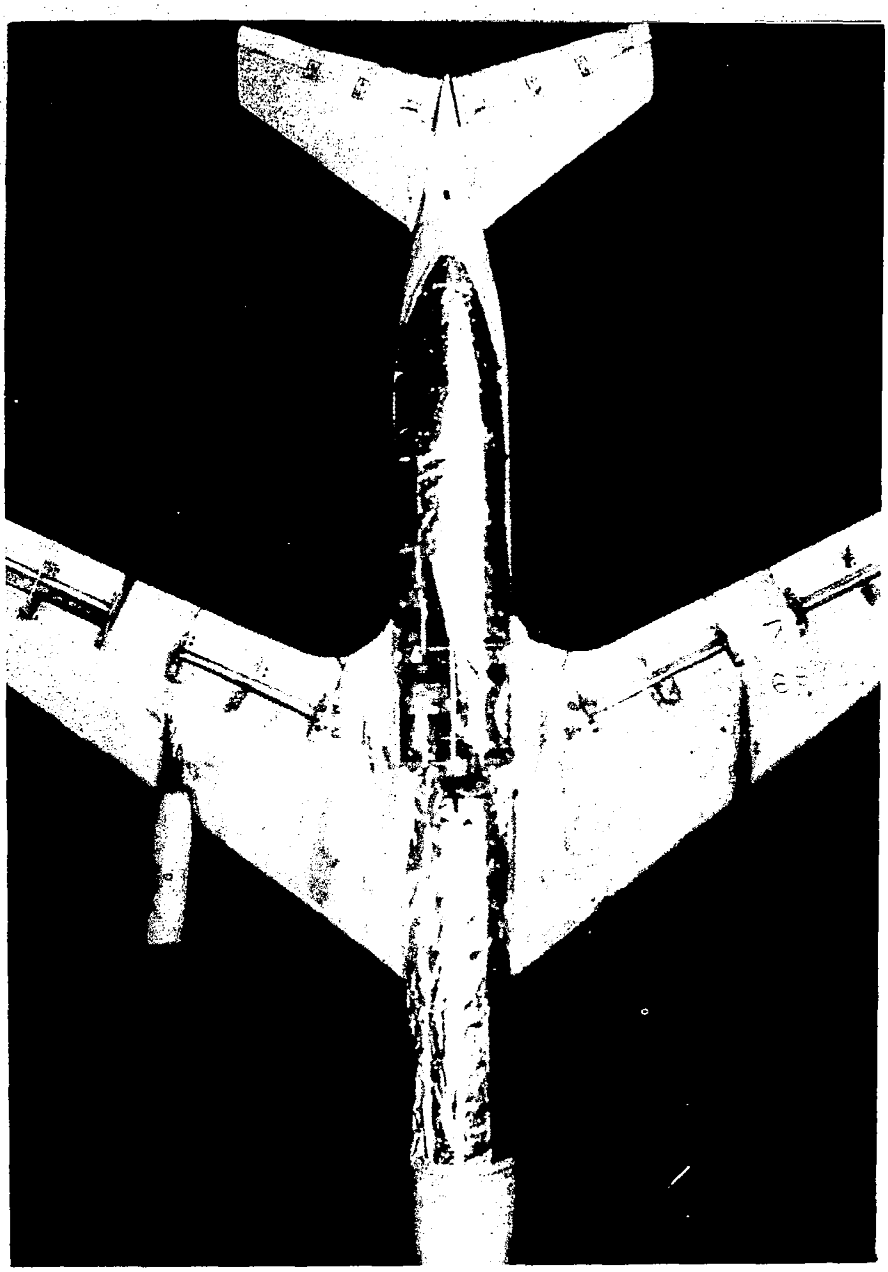
Figure 9.- Continued.



L-59-3092

(d) Twin hydro-skis (loading of 2,500 pounds per square foot). Very little damage.

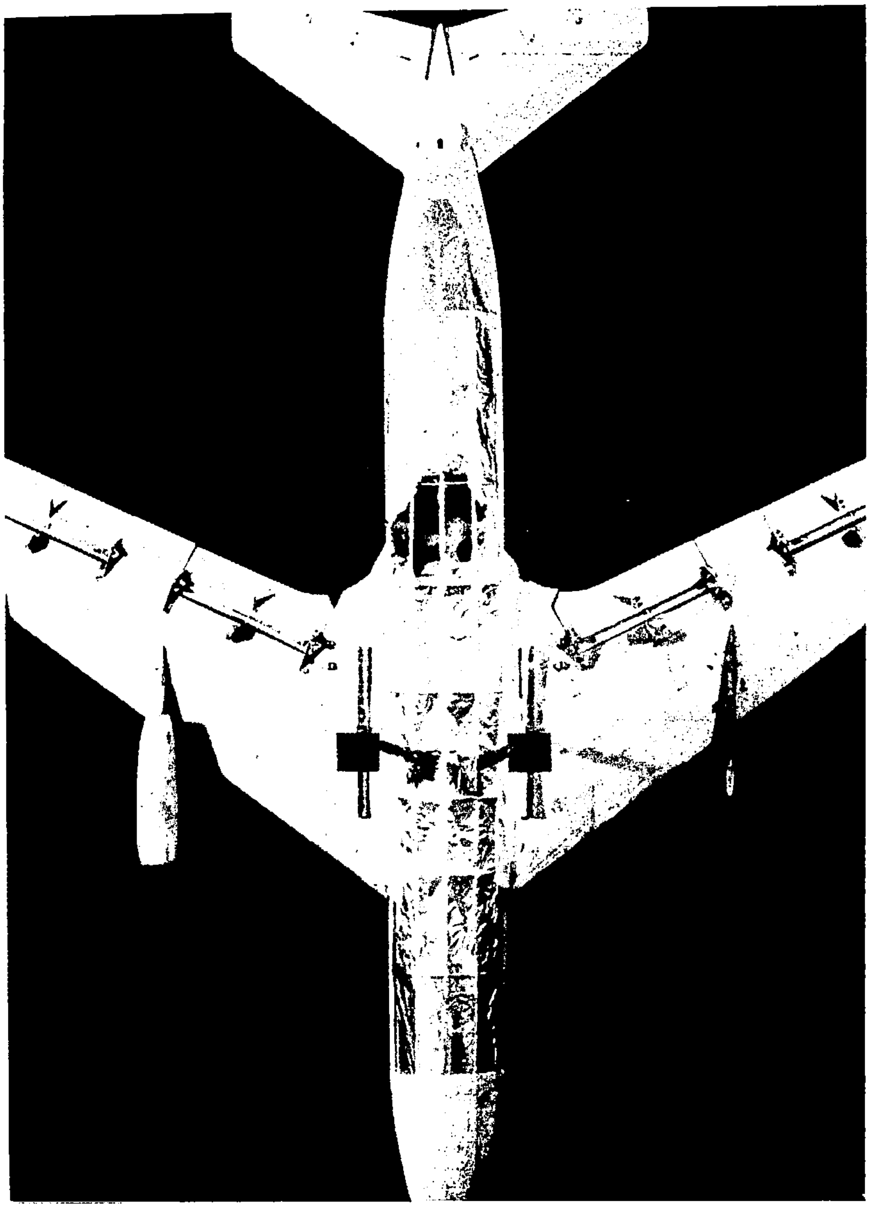
Figure 9.- Continued.



L-59-3093

(e) Twin hydro-skis (loading of 4,400 pounds per square foot). Moderate damage to midportion of fuselage bottom.

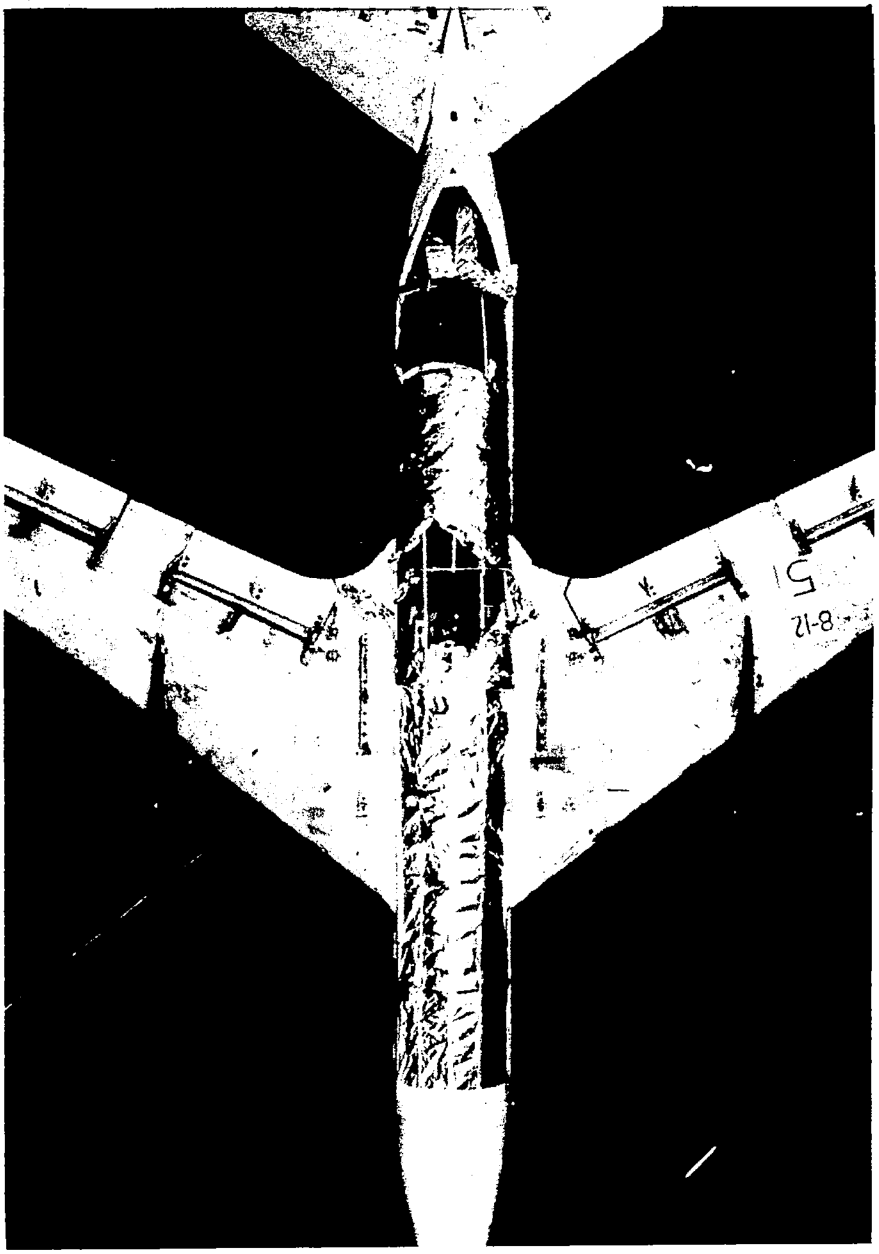
Figure 9.- Continued.



L-59-3094

(f) Twin hydrofoils (loading of 7,500 pounds per square foot). Moderate damage to fuselage just aft of wing.

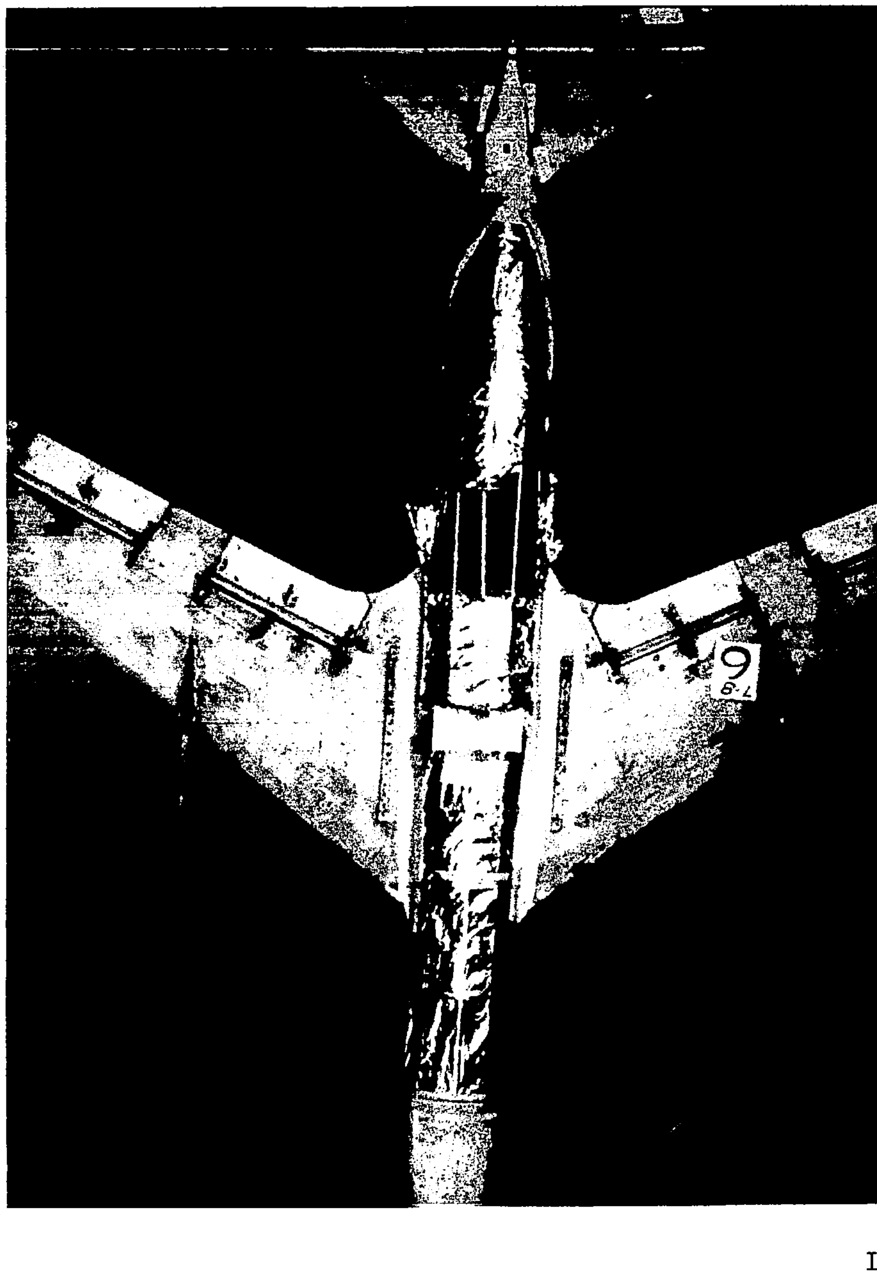
Figure 9.- Continued.



L-59-3095

(g) Twin hydrofoils (loading of 13,000 pounds per square foot). Appreciable damage to rear part of fuselage bottom.

Figure 9.- Continued.



L-59-3096

(h) Single hydrofoil (loading of 8,300 pounds per square foot). Moderate damage to fuselage just aft of wing.

Figure 9.- Concluded.

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30-33,35,36,38,40-43,45,48,49,52.